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***RESIDUAL EXPLOSIVES IN SOILS COMING FROM BURIED
LANDMINES***

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Abstract

The aim of this work was to determine the level of explosives-related chemicals in the soil around buried landmines. The site had seven types of unfused landmines buried two and three years prior to the sampling. Samples were collected on the surface of the soil and at different levels in the subsoil down to the landmine. The chemical analysis showed that 2,4-DNT was present at concentrations in the soil slightly higher than 2,4,6-TNT. The level of explosives was found to be below 100 ppb w/w for a large number of samples. In some cases, explosives concentrations were higher than 100 ppb but very rarely in the ppm w/w range. Due to the low concentrations and high soil/air partition coefficients, it appears that these buried landmines would not be detectable by any existing electronic noses nor by dogs. However the fact that dogs do find buried landmines suggests that fused landmines may leak more than an unfused one and lead to a much higher concentration of residual explosive in soil.

Résumé

Le but de ce projet était de déterminer le niveau de composés chimiques reliés aux explosifs présents autour de mines enfouies. Le site contenait sept types de mines non activées et enfouies deux et trois ans avant l'échantillonnage. On a prélevé des échantillons à la surface du sol ainsi qu'à différents niveaux dans le sol jusqu'à la mine. Les analyses chimiques ont montré que le 2,4-DNT était légèrement plus concentré dans le sol que le 2,4,6-TNT. Le niveau d'explosifs enregistré était en dessous de 100 ppb m/m pour un grand nombre d'échantillons. Dans certains cas, la concentration était supérieure à 100 ppb, mais se chiffrait très rarement au niveau des ppm m/m. En raison de la faible concentration et du coefficient élevé de partage sol/air, il s'avère que les mines enfouies ne sont pas détectables par un nez électronique ni par celui d'un chien. Cependant, le fait que les chiens soient capables de détecter les mines suggère qu'une fois activées les mines peuvent occasionner des fuites plus importantes et amener des concentrations beaucoup plus élevées d'explosifs résiduels dans le sol.

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Executive summary

It is quite clear that the detection of landmines is a fundamental need for military and humanitarian operations. It is a very costly and laborious activity that could be significantly improved by having a more sensitive and selective universal detector. Metal detector is still considered to be the best system but suffer from the large number of false alarms and has a lack of sensitivity for plastic mines having low metal content. Tremendous research has been directed toward the development of sensors having a very high probability of detection with a low false alarm rate. The idea of finding buried landmines with Trace Explosive Detectors (TED) gained attention by the fact that dogs detect mines. In fact, the existing TED systems can be more sensitive than a dog's nose, which in principle increase the potential of this technology. Also, TED would be an attractive technology because it detects the main ingredient present in all mine types, the explosives.

Over the years Defence Research Establishment Valcartier (DREV) has done research activities on the development of a trace explosive Detector specifically design for landmine detection. The USA has also evaluated electronic nose technologies through DARPA activities in order to develop a hand-held system for this application. These US efforts also included field-testing of TED prototypes and some studies on the understanding of the mechanism used by dogs. However there has been almost no studied reporting the level of any vapour or residual explosives evolving from buried landmines. It was fundamental for our program as well as for DARPA and the sensor developers to identify the concentration of the chemical source emanating from buried landmines. This report is the result of a study aimed at determining the level of explosives found in a large number of soil samples collected at the surface and deeper down to the mines. Soil samples were collected on the landmine site located at the Defence Research Establishment Suffield (DRES). This studied is the result of a collaborative effort with the US Army Cold Region Research and Engineering Laboratory.

From these experiments performed on unfused buried mines, it was quite clear that the concentration of explosive-related chemical in the air at the surface of a buried mine was too low to be detected by an electronic nose or by a dog's nose. With such a low concentration it is hard to believe that dogs can detect buried landmines in such hard conditions. Consequently, it was suspected that fused mines would lead to a much higher concentration of explosives in the soil or in the air at the soil surface. For safety reasons, this aspect was not evaluated in this study.

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Sommaire

Il est indéniable que la détection des mines est un besoin fondamental pour les opérations militaires et humanitaires. Ces opérations sont très coûteuses et laborieuses, et pourraient être améliorées de façon significative au moyen de détecteurs universels plus sensibles et sélectifs. Le détecteur de métal est toujours considéré comme étant le meilleur système, mais il a le désavantage d'engendrer un grand nombre de fausses alarmes et manque de sensibilité aux mines de plastique à faible contenu métallique. De nombreuses études et recherches ont été effectuées en vue de développer des capteurs ayant un degré élevé de détection et un faible taux de fausses alarmes. L'idée de trouver des mines enfouies en utilisant un détecteur d'explosifs en trace (DET) provient du fait que les chiens sont capables de détecter les mines. En fait, les DET existants peuvent être plus sensibles que le nez d'un chien, ce qui augmente en principe le potentiel d'une telle technologie. Aussi, DET serait une technologie attrayante puisqu'elle détecte l'ingrédient principalement le plus souvent présent dans tous les types de mines, l'explosif.

Ces dernières années, le Centre de recherches pour la défense Valcartier (CRDV) a procédé à des évaluations et des travaux de recherches sur la mise au point d'un détecteur d'explosifs en trace, spécialement conçu pour la détection des mines. Dans le but de mettre au point un système manuel pour cette application, on a récemment évalué, dans le cadre du programme DARPA (É.-U.), les technologies basées sur le nez électronique. Ces efforts américains portaient également sur la mise au point de prototypes DET, ainsi que sur l'étude de la compréhension des mécanismes de détection d'explosifs par des chiens. Cependant, il n'existe à peu près aucune étude publiée traitant du niveau de vapeurs et de résidus d'explosifs provenant de mines enfouies. Il était alors fondamental pour notre programme, ainsi que pour DARPA et les développeurs de capteurs de déterminer la concentration des ingrédients chimiques provenant de mines enfouies. Ce rapport est le résultat d'une étude visant à déterminer les niveaux d'explosifs qui se retrouvent à la surface du sol et plus profondément jusqu'à proximité de la mine. Les sols ont été échantillonnés dans un champ de mines situé au Centre de recherches pour la défense Suffield (CRDS). Cette étude est le résultat d'un effort de collaboration avec l'US Army Cold Region Research and Engineering Laboratory aux É.-U.

Selon les expériences effectuées sur des mines enfouies et non activées (sans détonateurs), il est évident que les vapeurs d'ingrédients reliés aux explosifs sont trop faibles à la surface du sol pour être détectées par un nez électronique ou par celui d'un chien. Il est difficile de croire qu'un chien pourrait les détecter à une si faible concentration. Par conséquent, on suppose que la présence du détonateur sur la mine pourrait provoquer des fuites plus importantes et montrer des concentrations d'explosifs beaucoup plus fortes que dans le cas qui nous intéresse (mines non activées). Cependant, pour des raisons de sécurité, on n'a pas procédé à une telle évaluation.

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1.0 INTRODUCTION

The detection of buried landmines is recognized as an urgent operational need for military and humanitarian activities. In fact, it is estimated that 100 million mines are buried around the world. This number is increasing each year and the scientific community is looking for a new sensor or a combination of sensors that would improve demining operations. Many technologies have been evaluated and a tremendous amount of work has been done to improve the performance of various sensors. At present, no sensors have shown overall performance superior to that of a metal detector or a dog's nose. Since the detection capability of the current chemical sensors, mostly between 10-100 ppt v/v (10^{-12}) can be similar and sometimes better than that of a dog's nose (Refs. 1, 2 and 3), it was assumed that a Trace Explosive Detector (TED) would also be able to detect the presence of buried landmines. This stimulated efforts at DREV (Ref 4,5,6,7) and in US (Refs 8,9,10) to develop a new TED with a lower detection limit and acceptable selectivity. Except for some preliminary data reported by George, et al. (Ref. 11), very little research had been dedicated to the residual explosives' concentrations in the soils coming from buried landmines. As underlined by Phelan and Webb (Ref. 12) the chemical vapours evolving from buried landmines can come from a permeation through the plastic case or through the seals and seams, and from the initial surface contamination of the case as determined by Jenkins et al. (Ref 13, 14). To evaluate the rate of evolution of the explosives, some modelling efforts have been made by Phelan and Webb (Ref 12) and at DREV (Ref 15) to quantify the vapour from buried landmines (Refs. 16). The acquisition of field data for concentrations in the soil and in the vapour phase is of primary importance to the development of any chemical sensor. Very recently, Jenkins et al. published a large amount of results on the Chemical Signature in soils samples collected near buried landmines at Fort Leonard Wood (Ref 17). The following DREV report contains the results of a complete evaluation of the residual explosives in the soils coming from various types of buried landmines at the Suffield mine site. The mines were unfused and had been buried for three years at the Defence Research Establishment Suffield (DRES).

2.0 EXPERIMENTAL PROCEDURE

2.1 Landmine site and soil sampling

Landmines were buried in a road located in a controlled area far from any building containing explosives. The road was prepared for this trial with a soil mainly composed of gravel and clay. This soil was specifically taken from an area clear of any residual explosives. This was also confirmed by analysis of blank soil samples taken on the road. All mines planted were unfused and contained TNT or a mixture of TNT and RDX. The seals used for the storage of mines were kept in place for this study. Burials were made in holes dug two weeks before any item was planted. The holes were separated by at least 5 meters in order to avoid cross-contamination between sites. All mines were put directly in their corresponding holes. At no time was any mine placed on the surface of the road beside its hole prior to planting. Finally, the mines were covered one by one with soil by using a clean shovel. The depth of the buried mines was around 2.5 inches (6.4 cm). The site contained anti-tank (AT) and anti-personnel (AP) mines of the following versions: TMA-3, TMA-4, TMA-5A, Mk-7 and M-21 for AT mines and PMA-1A, PMA-3 for AP mines. Four AT mines of each version were present on the site while for the AP mines two PMA-1A and three PMA-3 were present. The sampling campaign was made on 25 buried landmines present on the site.

Soil samples were collected at the soil surface after two and ten months of burial. More complete soil sampling campaigns were made after two and three years. The soil sampling procedure for the soil collected after two years was the following: 10 to 100 grams of soil were taken by using a new spoon for each site. Soil samples were collected at three depths down to the mine. Care was taken to leave part of the soil undisturbed for a further soil sampling campaign (third year). With the low concentrations present, it was found that the cross contamination was negligible so a new spoon was not necessary for each sample. As a consequence, the sampling for the next campaign (after three years) was slightly modified to use only one shovel that was cleaned with a towel between each sample. In order to reduce the metabolization process of explosives (Refs. 17, 18, 19 and 20) the soil samples were shipped frozen to the Defence Research Establishment Valcartier (DREV) and to the Cold Regions Research and Engineering Laboratory (CRREL) and were stored at 5°C until the analysis was performed.

2.2 Chemical analysis

The chemical analysis were performed by using a modified Environment Protection Agency procedure, EPA 8330 (Ref. 21) combined with a Gas Chromatograph Electron Capture Detector (GC- μ ECD or a GC-ECD) method developed by Walsh and Ranney (Ref. 22). The procedure was the following: 2 g of soil were added to a volume of 5.0 mL of acetonitrile and placed in the ultrasonic bath for 18 hrs (cooled). The supernatant with suspended soil

particles was then filtered by using a Millex-SR filter unit or through a 0.45 micron Acrodisc nylon filter unit. The acetonitrile extract containing the residual explosives was then injected directly into the GC-ECD system. A volume of 1.0 μL was injected in the case of the GC- μECD while 10 μL was injected into the GC-ECD system. A calibration curve was made by using a standard 1 mg/mL (1000 ppm) solution mainly containing RDX, 2,4,6-TNT, 2,4-DNT, 2,6-DNT and their amino metabolites 4-Amino 2,6-DNT and 2-Amino 4,6-DNT. The standard solution of 1 mg/mL (1000 ppm) was supplied by Accu Standard (New Haven, Connecticut). Dilution were then made with acetonitrile to obtain solutions of 10.0, 1.0, 0.75, 0.50, 0.10, 0.05, 0.01, 0.005, 0.001 ppm. The standard solutions were always freshly prepared and the solutions from soil samples were always analyzed immediately after the extraction process had been completed. The concentrations of the solutions in ppm were then converted to the concentration in the soil sample in ppb w/w unities (10^{-9}) by using a multiplication factor of 2500. This factor consider that the soil sample solutions were prepared by using 2 g of soil treated with 5 mL of acetonitrile

The gas chromatograph- μECD and ECD systems used were the Hewlett Packard system HP-6890. For the μECD system the GC column was a 6 m x 0.53 mm HP-5 (5% phenylmethyl polysiloxane) while a 10 m column was used for the ECD system. The temperature of the injector was 250°C, while the detector was at 280°C. After the injection the oven was kept at 100°C for two minutes and then increased up to 200°C at a rate of 10°C/min. Finally, the temperature was increased at 240°C with a heating rate of 20°C/min. The gas velocity was 82 cm/s for the 6 m column and 92 cm/s for the 10 m column.

Theoretically a very low detection limit, down to about 0.1 ppb w/w, can be obtained for a solution containing only explosives. However, the practical sensitivity limit is due to the presence of other organic ingredients in the soil which can be present at different level for each sample. In our case, a more realistic detection limit for most soil samples was found to be around 10 ppb w/w for 2,4-DNT 2,4,6-TNT, 2-AminoDNT and 4-AminoDNT. In a few cases, the gas chromatogram allowed the detection of these ingredients down to 1 ppb w/w. For RDX, the detection limit was around 40 ppb w/w.

3.0 RESULTS AND DISCUSSION

The preliminary data reported on this site (Ref. 7) showed that the concentration of explosives in soil shortly after the burial of mines was generally below 0.8 ppb w/w for TNT and below 7.4 ppb w/w for RDX. These measurements were taken by a highly sensitive soil extraction Gas Chromatograph Ion Mobility Spectrometry system (GC/IMS) design for mine detection applications (Ref. 5). Ten months after the burial process another sampling was done. It was found that the explosive level in the soil had gradually increased with time. After two years a more complete evaluation was performed to have a better overall picture. Finally, after three years, additional sampling was performed consisting of a larger number of samples around a single mine and also under a buried landmine.

A typical gas chromatogram of a soil which has remained in the presence of a buried mine for three years is shown in Figure 1. The main contaminants found in most soil samples were mainly 2,4-DNT, 2,4,6-TNT, 2-Amino DNT and 4-Amino DNT. In a few cases, RDX was observed (retention time 9.5 min) at concentrations between 40-100 ppb w/w. The following were not present at detectable concentrations in most soil samples: 2,6-DNT, 1,3-DNB, NB, o-NT, m-NT, p-NT, 3,5-DNA, 2-Amino-6-NT, 2-Amino-4-NT, 4-Amino-2-NT and Tetryl. It should be pointed out that during the chemical analysis 2,4-DNT and 2,4,6-TNT were always the explosives-related chemical present at highest concentration.

To have a better overall picture of the explosives in soil samples the large amount of data was compiled and is described in Figures 2 and 3. These data show the distribution in ppm ($\times 1000$ to get ppb unities) of the broad range of concentrations for the 265 samples collected. The distribution shows that the level of explosive is strongly present in the low concentration part of the diagram, more specifically below 0.01 ppm (10ppb). In comparison with the low residual explosives found for most samples after 10 months (Ref. 7), the explosive level in soil had increased in the following months. However, by comparing the two figures we see that the level of the residual explosives in soil remains fairly constant from two to three years of burial. At this point (after two and three years) the slight difference in concentration distribution is probably due to the effect of the water present in soil. The wetting and drying cycles in the soil may be responsible for the transportation of the explosives in soils as recognized by Phelan and Webb. (Ref. 12) and thus may change the concentration profile. An important observation is that the explosives are not homogeneously distributed in soils leading to the very broad concentration profile described in Figures 2 and 3. In fact, we found large variations in concentration from different locations around a single mine. This probably reflects the non-homogeneity characteristics (ex: porosity and particle size) of the soil. For example, for TMA-3 mines buried for two years (not described in the figures) it was found that the level of 2,4,6-TNT was as high as 62 800 ppb w/w (62.8 ppm) in some areas, while other samples had a concentration lower than 100 ppb w/w. Another observation is that the surface layer of the soil (less than 1 cm deep) had lower level of explosives. This phenomenon shows that either transport to the surface is slow or the explosives at the soil

surface may lost by transformation or photodegradation. Samples with high concentrations of explosives-related chemicals were mostly found close to the mine casing.

To have a better idea of the distribution of these chemicals, extensive sampling was conducted around a single TMA-5 mine that had been buried for three years. Table I contains the data of the soil analysis. The sampling was done at different depths in the soil, namely S: surface, M: medium, D: deep, close to the mine surface, DD: deep around the mine and DDD: under the mine casing. For each depth, four samples (namely a, b, c, d) were taken around the center of the mine (namely C) and some were taken on the edge of the mine casing (namely E). The very low explosive concentration at the surface and the higher concentration deep in the soil are again confirmed. However, for all other samples, the explosives seem to be heterogeneously distributed in the soil.

It was also found that the mine types with the highest level of residual explosive were TMA-3 and TMA-4. For the TMA-4, the high concentration of 2,4-DNT and 2,4,6-TNT probably results from a high flux rate through fiberglass casing compared with other types of casings. The explosives are leaking better through the fiberglass mine casing as is also observed (Ref. 7) in the case of a plastic bag. In fact, we found that a block of TNT wrapped in a thin plastic bag and buried in the ground rapidly causes a high concentration of explosives in the soil. However, anti-personnel mines with plastic or metallic casings and anti-tank mines with a metal casing showed much lower concentration of explosives in soils.

An important observation is that 2,4-DNT was slightly more concentrated in the soil than 2,4,6-TNT. This has also been reported by George et al. (Ref. 11) for soils sampled at a research minefield at Fort Leonard Wood. Normally, a much higher TNT level is expected, due to the very low amount of 2,4-DNT present in the military grade TNT (Refs. 23-25). This phenomenon results from the fact that 2,4-DNT has a much higher vapour pressure than 2,4,6-TNT (Refs. 26, 27 and 28) and is more prevalent in the equilibrium vapour associated with military grade TNT (Ref. 29). As a consequence, even though 2,4-DNT is only present at less than one percent in military grade TNT, it evaporates more through the mine casing or through the seal. The vapours are condensed and absorbed in the water phase present in soils as well as in the pores present in soil particles. Since 2,4-DNT is present at higher concentrations in the soil combined with its higher vapour pressure, it is evident that the vapour phase at the surface of the soil will contain much more 2,4-DNT than 2,4,6-TNT. This result has also been confirmed by the partition and diffusion based calculations (Refs. 12 and 15) and physical measurements by Jenkins et al. (Ref. 29). As a consequence, a chemical sensor based on vapour detection should target 2,4-DNT as opposed to 2,4,6-TNT.

It is expected that the proportion of the related TNT derivatives may be very different from different sites. By comparison with the results from Fort Leonard Wood it was found that the

4-Amino and 2-Amino DNTs were less present in the Suffield site. Such a difference may be hard to explain due to the complexity of the metabolism processes present in soils and the kinetics associated with these processes. For example, it is known that the metabolism of a single micro-organism may be influenced by the oxygen and the nitrogen concentrations as well as by the level of water contained in the soil. The presence of vegetation at Fort Leonard Wood is an evidence of the difference in soil characteristics. Also, it was not so evident that the soil at Suffield had the same type of micro-organisms as for Fort Leonard Wood. This may also affect the metabolism process and modify the proportions of TNT, DNT and Amino DNTs. Finally, the porosity and nature of the soil (clay, sand, etc.) is different and may lead to a better adsorption of the Amino DNT, for example. This would probably reduce the reactivity of the micro-organism.

Combining the Suffield mine site results with the partition coefficient measurements or by our semi-empirical approach (Ref. 15), it is evident that the concentrations of vapours in a minefield are much lower than the detection limit of any existing detection system or dog's nose. It was concluded (Refs. 12 and 15) that the explosive vapour at the soil surface was lower than the ppq level (10^{-15}) and should never been detectable. In a first approximation it was proposed that a dog could detect buried landmines in a two-step process. First, a dog could identify a smell other than that of explosives related to the burial process of a mine (a human scent or a very volatile solvent, for example). Second, a dog would confirm the existence of a mine by detecting the explosives present in soil particles. Such a mechanism is difficult to believe since we have never seen any signal in the chromatogram more concentrated than 2,4-DNT or 2,4,6-TNT. It is also difficult to believe that a highly volatile solvent undetected in military grade TNT and lower in concentration than 2,4-DNT in soils would still be present in the vapour phase around buried mines. According to Johnston et al. (Ref. 30), the detection mechanism of buried landmines by dogs is still unclear at the moment. The presence of the fuse on an activated landmine that could cause more leakage of explosives through the seal is also an unknown effect. However, for safety reasons this aspect was not evaluated in this study.

4.0 CONCLUSION

The soils around unfused buried landmines contain mainly 2,4-DNT and 2,4,6-TNT in the ppb w/w range (100 ppb and less for a large number of samples). The explosives are not homogeneously distributed in the soil and, in a few cases, the concentrations may be as high as the ppm w/w. However, the average concentration of explosive-related chemical was found to be below the detection limit of our analytical method (below 10 ppb w/w). 2,4-DNT concentration was found to be higher than 2,4,6-TNT in soils as a result of a stronger vapour pressure of 2,4-DNT. Concentration of 2-Amino and 4-Amino-DNTs were lower at Suffield than in Fort Leonard Wood minefield due to the differences in the metabolization processes and soil characteristics (vegetation, porosity, moisture and, possibly, type of microorganism). Finally, it was suspected that the concentration of explosives would be much higher in the case of an activated buried mine (with a fuze).

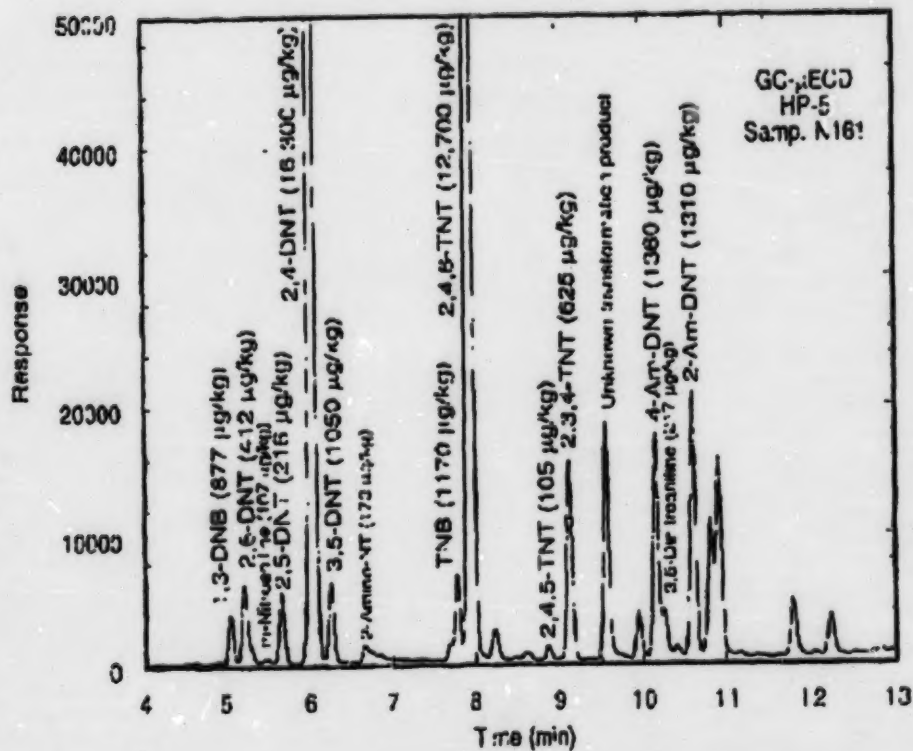


Figure 1. GC Chromatogram of the explosives contained in a soil sample

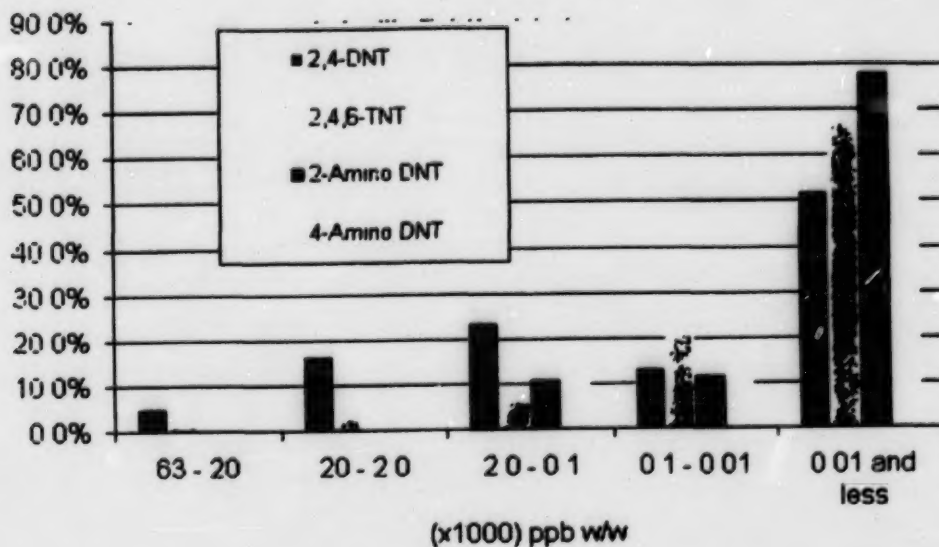


Figure 2. Concentration profile found in soil samples after 2 years (150 samples)

* Unities on figure are expressed in ppm but should be multiplied by (x1000) to obtain ppb.

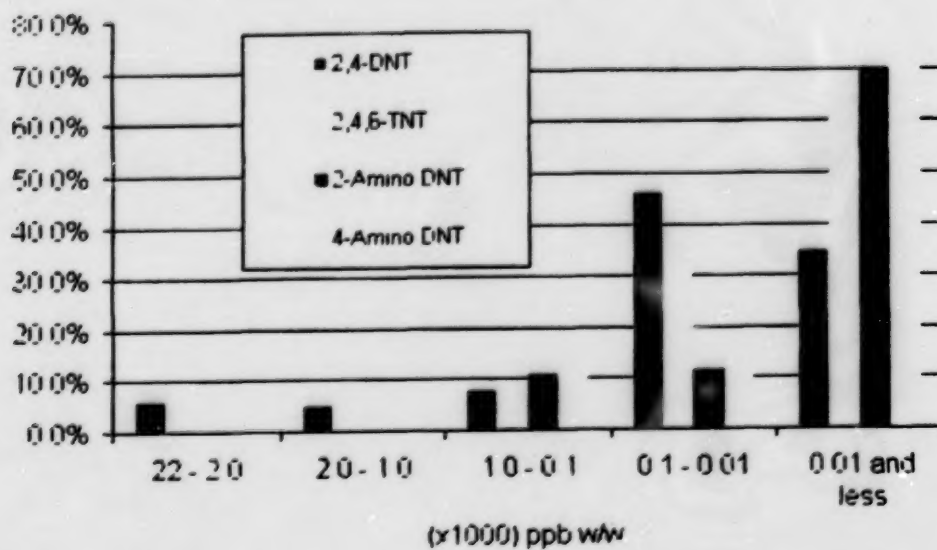


Figure 3. Concentration profile found in soil samples after 3 years (115 samples)

* Units on figure are expressed in ppm but should be multiplied by (x1000) to obtain ppb

Table I - Soil sample concentration (ppb w/w) from a TMA-5 buried landmine					
DEPTH ¹	LOCATION ²	2,4-DNT	2,4,6-TNT	2-AMINO DNT	4-AMINO DNT
S	Ca	ND	61,9	ND	ND
S	Cb	ND	ND	ND	ND
S	Cc	ND	67,8	ND	ND
S	Cd	ND	ND	ND	ND
S	Ea	45,3	59,0	ND	ND
S	Eb	ND	ND	ND	ND
S	Ec	45,6	78,8	ND	ND
M	Ca	49,1	75,2	3,1	2,9
M	Cb	ND	ND	ND	ND
M	Cc	ND	ND	ND	ND
M	Cd	73,1	60,8	4,4	3,4
M	Ea	48,0	ND	ND	ND
M	Eb	47,3	ND	ND	ND
M	Ec	45,7	64,9	3,5	3,2
D	Ca	64,6	67,3	4,8	7,0
D	Cc	122,0	3,5	18,8	19,1
D	Cd	197,0	60,4	10,3	12,6
D	Ea	85,1	ND	1,8	1,7
D	Eb	71,9	64,5	7,8	6,6
D	Ec	63,2	60,9	2,8	2,7
D	Ed	60,3	59,1	3,5	3,5
DD	Ca	1253,0	135,0	41,3	46,0
DD	Ea	57,4	ND	4,3	4,6
DD	Eb	145,0	66,5	16,1	16,8
DD	Ec	443,0	63,9	7,7	9,2
DD	Ed	59,3	69,7	2,8	2,6
DDD	Cb	1558,0	226,0	46,3	53,8
1. Depth of the sampling where; S: Surface sample; M: medium sample; D: deeper in the soil; DD: Very deep and close to the mine surface; DDD: Under the mine. 2. Location over the mine where Ca: Center location a; Ea: Edge of the mine location a. 3. ND means not detected.					

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List of symbols/abbreviations/acronyms/initialisms

AP	Anti-Personnel Mine
AT	Anti-Tank Mine
CRREL	US Army Cold Regions Research and Engineering Laboratory
DND	Department of National Defence
DNB	Dinitrobenzene
DNT	Dinitrotoluene
2-Amino DNT	2-Amino Dinitrotoluene
4-Amino DNT	4-Amino Dinitrotoluene
DARPA	Defence Advanced Research Project Agency (US)
DRES	Defence Research Establishment Suffield
DREV	Defence Research Establishment Valcartier
GC/ECD	Gas Chromatography/Electron Capture Detector
GC/IMS	Gas Chromatography/Ion Mobility Spectrometry
NB	Nitrobenzene
Ppm w/w	Parts per million weight/weight (10^{-6}) = ug/g
Ppb w/w	Parts per billion weight/weight (10^{-9}) = ng/g
Ppb v/v	Parts per billion Volume/volume (10^{-9})
Ppt v/v	Parts per trillion Volume/volume (10^{-12})
Ppq v/v	Parts per quadrillion Volume/Volume (10^{-15})
RDX	Hexogen or Cyclonite
TNT	Trinitrotoluene

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